



# P R O J E C T C E N T A U R

A COMPREHENSIVE DIRECT IMAGING EXOPLANET  
TECHNOLOGIES DEMONSTRATOR IN SPACE



***Centaur:*** A comprehensive direct imaging exoplanet technologies demonstrator in space.

***Centaur is a scientific and technology pathfinder for larger exoplanet missions with rapid and low-cost development***

## FACT SHEET

**Value Proposition:** Enabling direct imaging of exoplanets around nearby stars leveraging ARC experience and expertise in small sats and exoplanet detection.

- Technology and scientific pathfinder for critical direct imaging technologies. First flight of PIAA star light suppression system (Not sounding rocket).
- Constrain the exozodiacal light on Alpha Centauri A and B retiring the “dust” risk for other missions.
- Measure the visible (450nm) brightness of dust disks that can be resolved with centaur,

**Mission:** 1-year operations

**Instrument:** 15 cm off-axis corona graphic telescope, 1 band 450nm.  
 $10^{-7}$  raw contrast @  $1.6\lambda/D = 1.0''$

**Bus:** Millennium Space System, 27U off-the-shelf

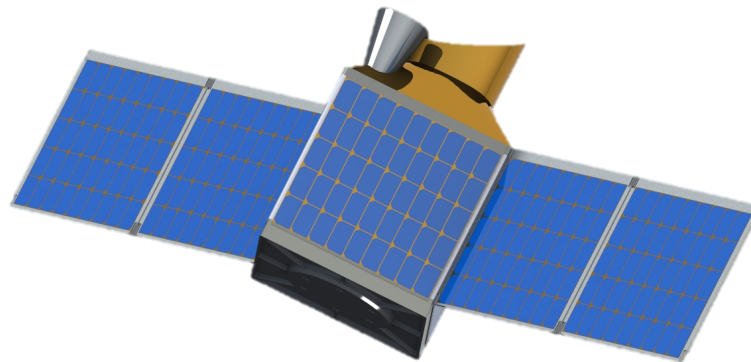
**Orbit:** LEO (400 to 800 km)  $28^\circ$  or  $90^\circ$

**Cost:** ~\$10M

**Project:** 3-year development  
1-year operation

**PI:** Eduardo Bendek

**SE:** Rodolphe De Rosee



*Centaur mission model*



## Abstract

NASA ARC proposes Centaur—a scientific and technology pathfinder for NASA’s planned series of direct-imaging exoplanet detection missions. Centaur’s objective is to advance existing Starlight Suppression Systems technologies from TRL-5 to TRL-7 in preparation for larger and more capable direct imaging missions. Centaur accomplishes this objective by observing the exozodiacal light in visible bands of two nearby star systems, in particular  $\alpha$ Cen A & B and  $\epsilon$ Eri. Accomplishing this objective of delivering unique disk and planetary formation science and retiring the exozodiacal light astrophysical risk directly enable future direct imaging missions. Centaur will perform educational goals involving students in the mission development and data reduction, as well as engaging kids with talk, tutorials and mission webpage that allows disseminating the exciting science that Centaur will enable.

Directly imaging and characterizing planets around nearby stars is becoming an increasingly important scientific goal as the planet occurrence rate increases with the latest results indicating 0.79 planets per star are smaller than 5 Earth sizes and have orbital periods between 50 and 300 days. In particular, for exo-Earths ( $\eta_{\text{Earth}}$ ) in the Habitable Zone (HZ) this rate could be as high as 55% per star for ranges of 0.5-2 Earth sizes and using the extended HZ definition in Kopparapu et al., 2013. As a result, the likelihood of finding a planet 5 times the size of Earth’s radius or smaller around any of the 5 closest F, G, K stars is almost 1; and of finding an exo-Earth in the HZ of those stars is approximately 95%. These rates not only make large (\$1B+) direct imaging missions such as EXO-C, EXO-S, and AFTA-C more compelling, but also present an opportunity to perform unique science with small telescopes at low cost and rapid development time.

A particularly interesting case is the Alpha Centauri A & B binary system. Its HZ extends from 0.7” to 1.6” and 0.4” to 0.95”, respectively, and where an Earth-like planet has a contrast ratio of  $1 \times 10^{-10}$  making it accessible using small-aperture telescopes. This unique astrophysical configuration of large angular separation and moderate contrast and a new technology development to control diffraction of binary stars, such  $\alpha$ Cen A & B has driven the design of a specialized mission called ACESAT. This particular mission and the larger ones mentioned before require advancing key technologies to TRL-7 and constraining the exozodiacal light level of target’s planetary systems.

Centaur may also have the capability to detect Neptunes in the outer regions of the  $\alpha$ Cen HZs that are not accessible to Radial Velocity instruments. It may also be capable of imaging candidate planets in  $\epsilon$ Eri. While these are clearly stretch goals for a mission of this scale, analysis indicates that the coronagraph’s resolving power will be adequate to do this. In addition, Centaur may have observing time to point at additional nearby star systems as a lower priority science objective.

Centaur is a single-instrument mission employing a stand-alone, compact, high-performance 15cm aperture coronagraphic telescope, integrated with an off-the-shelf 27U small satellite bus. The instrument has an inner working angle of  $1.6\lambda/D$ , which at 450nm is 1.0” allows access to most of the HZ of  $\alpha$ Cen A and part of B out to the stability limit of both stars at 2.5” or  $5\lambda/D$ . We expect Centaur to achieve a raw contrast of  $10^{-7}$  and a post-processing enhancement factor of 100 using Orbital Differential Imaging reaching



$10^{-9}$  total contrast for point sources and a factor of 20 on extended sources such disks by rolling the S/C.

The coronagraph that comprises the core of this instrument has been proven at vacuum and is currently at TRL-5. The Centaur development timeline advances the instrument design through a comprehensive test series that validates the optical performance of the full optical train, including the telescope components. The secondary mirror is the system stop, provides tip/tilt control, and is the first element of a PIAA based Starlight Suppression System. Centaur uses a 1024 actuator MEMS DM to correct wavefront errors and provide high-speed tip/tilt control. Centaur serves to space-qualify a compact, low-power-consumption DM controller being developed for this application. The scientific camera is based on a modified commercial Electron Multiplying CCD (EMCCD) detector, which is especially suited for low-light applications—in particular, exoplanet detection. The same camera technology is being considered for other NASA's large exoplanet missions such as WFIRST CGI and ACESAT. The former technologies, Multi-Star Wavefront and advanced post processing are the key direct imaging technologies advanced by Centaur. Centaur has a robust design that allows a graceful mission downscope if technical problems are encountered. Specifically, we add a calibration source to enable on-orbit validation of the DM, the new compact controller, the science camera, and the wavefront control algorithm even if the bus does not meet the pointing requirements.

The Centaur Project is a 4-year effort that designs, builds, and launches a small satellite based on a rapid, low-cost development plan that is synergistically aligned with NASA ARC's areas of expertise: cubesats, PIAA coronagraphs, and multi-star wavefront control. Centaur also builds on previous NASA investments to develop PIAA (APRAs and SAT, Belikov, Bendek) and the MSWC (APRA, Belikov 2014).

### Scientific goals

- Constrain the exozodiacal light on alpha Centauri A and B
- Measure the visible (450nm) brightness of disk stars that can be resolved with centaur:

	<i>Disk</i>	<i>Planet</i>
○ Fomalhaut:	17" to 20"	Too dim
○ Beta Pic:	0" to 100"	Too close
○ Epsilon Eridani:	6" and 11" to 23"	1.1"
○ Epsilon Indi	unknown	2.4"
○ Tau Ceti	9.6" to 14"	Too close

### Expected performance

- Aperture 15cm @450nm
- 1 band 10% bandwidth (keep it simple and optimize throughput)
- IWA @ $1.6\lambda/D = 1.0''$
- OWA @ $3.5\lambda/D = 2.5''$
- $1 \times 10^{-7}$  raw contrast
- Distance aCen A and B by 2018 =  $4.6''$  or  $7.5\lambda/D$



### Functional requirements

- Payload envelope: 20x15x30cm
- Weight: ~15kg
- Power: 25W max.
- Pointing: Accuracy +/-2" (Coronagraph pointing knowledge 0.001")
- Jitter stability: 0.3" for all frequencies.
- Data rate: 100KB/hr
- Memory: 4Gb
- Orbit: LEO, ideal Sun synchronous
- Mission duration: Min 6 Months, Ideal 1 year.

### Launch specifications

- Total Mass: 25kg
- Volume: 3x3x3U = 27U
- LEO ( $\geq 800\text{Km}$ ), Sun Synchronous orbit
- Alternative orbits: LEO, inc  $27^\circ$
- Expect Launch date: Q1 – 2017

### Direct imaging Exoplanet mission roadmap

Centaur is the first of series NASA's direct imaging exoplanet detection missions and it will serve as a comprehensive direct imaging exoplanet technologies demonstrator in space.

Table 1. Summary of NASA's of direct imaging exoplanet missions

	2017	2018	2020	2021	2022	2023	2024 and future
Mission	<b><i>Centaur</i></b>		<b><i>ACESAT</i></b>				<b><i>AFTA/EXO-C</i></b>
Cost	\$3M		\$175M				>\$2B
Science	Exozodi/Tech demo		Earth-like, only aCen				~Earth-like, +50 targets